PREPRINT UCRL- 81365

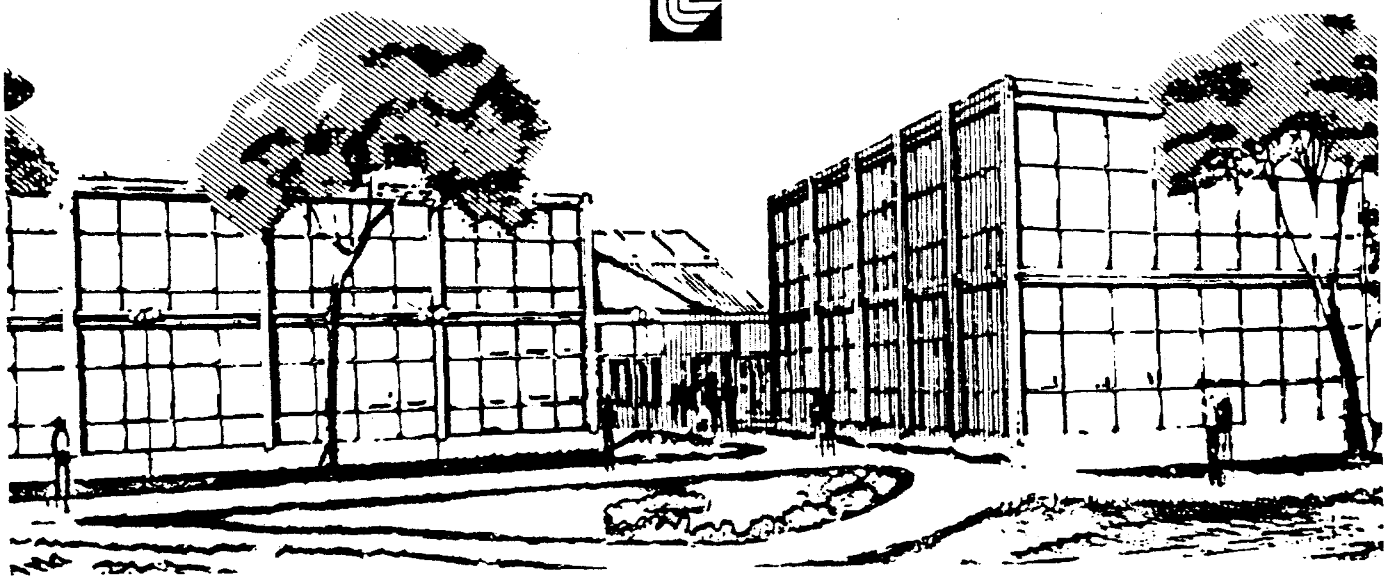
Lawrence Livermore Laboratory

DEVELOPMENT OF AN ACTIVELY MODELOCKED
AND Q-SWITCHED OSCILLATOR FOR LASER
FUSION PROGRAM AT LLL

D. J. Kuizenga

July 19, 1978

THIS PAPER WAS PREPARED FOR SUBMISSION TO
PROCEEDINGS OF THE CONFERENCE ON PICO-SECOND PHENOMENA,
SOUTH CAROLINA, May 24-26, 1978



DEVELOPMENT OF AN ACTIVELY MODELOCKED AND Q-SWITCHED OSCILLATOR FOR LASER FUSION PROGRAM AT LLL*

D. J. Kuizenga

Lawrence Livermore Laboratory
University of California
Livermore, California 94550

The large Nd:glass laser-fusion systems such as Argus and Shiva require short-pulse oscillators that are very reliable and predictable. The requirements go well beyond what can reasonably be expected from a passively mode-locked laser. An actively mode-locked and Q-switched oscillator has now been developed that is extremely reliable and predictable, and satisfies all the requirements for the present Nd:glass laser systems. These systems require pulses that are adjustable from less than 100 ps to more than 1 ns, with less than 5% shot-to-shot variation in pulse energy and pulse width. Single-pulse energy from 100 μJ to 1 mJ is sufficient.

An actively mode-locked CW Nd:YAG laser can provide the range of short pulses required [1,2] and is also sufficiently stable. It has been shown that under steady-state conditions the pulse width in this laser, mode-locked with an amplitude modulator, is given by:

$$\tau_p = \frac{(2\ \ln 2)^{1/2}}{\pi} \frac{(g_o)^{1/4}}{\theta_m^{\ 1/2}} \frac{1}{(f_m \cdot \Delta f)^{1/2}} , \tag{1}$$

where

θ_m = depth of modulation

g_o = round-trip amplitude gain

Δf = linewidth

f_m = modulation frequency

For typical laser parameters, pulses shorter than 100 ps can be obtained; and with the use of an etalon in the cavity, longer pulses of up to 1 ns or more can be obtained, depending on the cavity length.

*Work performed under the auspices of the U.S. Department of Energy, Contract W-7405-eng-48.

A typical CW mode-locked Nd:YAG laser gives only a few nanojoules in a single short pulse. This can be increased by more than four orders of magnitude by simultaneously Q-switching the laser. However, the buildup time in a typical Q-switched laser is not long enough for the short-pulse generation process to reach steady state. To obtain good mode locking in the Q-switched Nd:YAG laser, the buildup time of the Q-switching has to be increased. Several workers [4-7] have developed techniques to do this in an attempt to obtain steady-state mode locking before the Q-switched pulse train is obtained.

We have now further developed a method that allows the mode-locking process to go to its steady state condition before the laser is Q-switched.[8] This is done by pumping the laser quasi-cw for about 5 ms. During this time, the loss in the Q-switch is such that the laser will just slightly go above threshold. The active modulator is on during this time, and the laser oscillates quasi-cw for a period long enough to obtain stable transform-limited short pulses. At the end of this prelase period, the laser is Q-switched, and a train of stable, short pulses is obtained.

Three conditions have to be satisfied during this prelase period. First, the short pulse envelope has to approach a steady state value. It has been shown [3] that the pulses are within 5% of the steady state value after a number of round trips M given by:

$$M = \frac{0.38}{g^{1/2}\theta_m}\left(\frac{\Delta f}{f_m}\right), \tag{2}$$

where g is the roundtrip amplitude gain during the prelase period, and the other parameters are defined for (1). The dominating factor here is f/f_m, which is typically on the order of 10^3, and hence for a typical mode-locked Nd:YAG laser, it takes about 10 to 100 μs for the short pulses to approach their steady-state value. This is easily satisfied during the prelase period.

The prelase period must also be long enough for the pulses to become transform-limited. It may happen that even though the short pulse envelope has reached its steady state value, the pulse still has considerable substructure and may be chirped, etc. This type of substructure is smoothed out by repeated passes through the finite bandwidth of the active medium (or etalon). If one considers the narrowing of the spectrum on repeated round trips, it can be shown that the spectrum is within a factor of two from the steady state, transform limited spectrum after a number of round trips M given by:

$$M > \frac{0.5}{g^{1/2}\theta_m}\left(\frac{\Delta f}{f_m}\right) . \tag{3}$$

This is essentially the same as the condition for the short pulse envelope to reach steady state. A much more severe condition to obtain perfect transform limited pulses is given by:

$$M > \frac{0.35}{g}\left(\frac{\Delta f}{f_{ax}}\right)^2 , \tag{4}$$

where f_{ax} is the axial mode spacing of the cavity. This is the condition required to get single axial mode operation without modulation. With the modular on, this condition means that we get this single axial mode plus its sidebands produced by the modulator, and hence a perfect transform limited pulse. For a typical mode-locked Nd:YAG laser, it can take as much as several milliseconds to satisfy this condition. This condition is more severe than is actually required to get good pulses from a Nd:YAG laser.

Finally, when the laser goes above threshold at the start of the prelase period, there are the usual relaxation oscillations. These have to die out so that the laser can oscillate quasi-cw. It usually takes a few upper level lifetimes for this to happen and hence in a Nd:YAG laser, these relaxation oscillations die out in about 1 ms. In practice it is found that a prelase period of about 3 to 5 ms gives very good operation of this type of laser.

A typical arrangement for this type of oscillator now in operation on Argus and Shiva is shown in fig. 1. An acousto-optic modulator and Q-switch were used. The modulator, as well as the Q-switch, had direct water cooling of the transducer (35° Y cut $LiNbO_3$) to ensure stable thermal conditions in the modulator. The modulator and Q-switch, as well as the Nd:YAG rod, were all cut as Brewster's angle to completely eliminate any spurious etalon effects or multiple reflections between components in the laser cavity. This gave stable and predictable short pulses from this laser, and also reduced the noise level between pulses to a minimum.

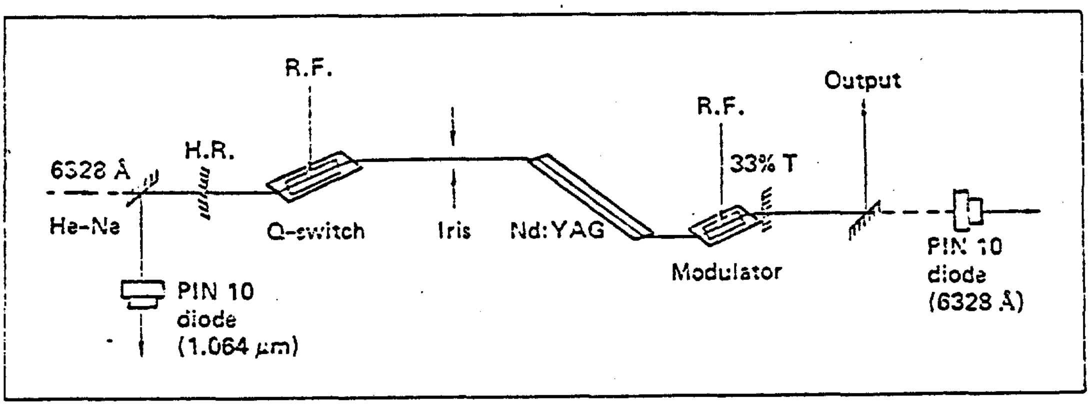


Fig.1 Typical arrangement of modelocked and Q-Switched Nd:YAG laser. Pulse repetition rate is 5 or 10 pps.

It was quite difficult to obtain stable, quasi-CW pumping of the lamps to satisfy the ± 5% stability of the pulse energy. The final and successful arrangement consisted of a bank of power transistors to regulate the voltage of a number of capacitors. In addition, a transistor bank in series with the lamps provided feedback regulation of the simmer and peak currents through the lamps adjustable from 1 to 5 ms and shot-to-shot stability of better than 0.3%. This was sufficient to give good operation of the laser.

We found that the pre-lase signal is a very good indicator of how well the laser is mode-locked [8]. It was found that with the modulator off, the initial relaxation oscillations are quite irregular; but with the modulator on, these relaxation oscillations become very smooth and regular. For a small change in cavity length (∿25 μm) the relaxation oscillation continues through the entire pre-lase period. These driven oscillations occur for length changes longer and shorter than the optimum length. It is precisely the combination of these characteristics that allows one to easily adjust the laser for optimum mode locking, and one only needs a very slow detector and oscilloscope to do this. Many other laser problems can be diagnosed from this pre-lase period, such as higher-order transverse modes.

An optical correlator was used to measure the pulse widths from the Argus laser. Although in principle similar to that described before [3] this correlator was considerably improved to routinely do very accurate short-pulse measurements. Figure 2 shows the range of short pulses available from this oscillator. Note that with the aid of a 2.5 mm and 11 mm uncoated quartz etalon, the required pulsewidth range from 100 ps to 1 ns can be obtained. Figure 3 shows the energy in a single, selected pulse near the peak of the pulse train. For strong modulation, there is some reduction in output

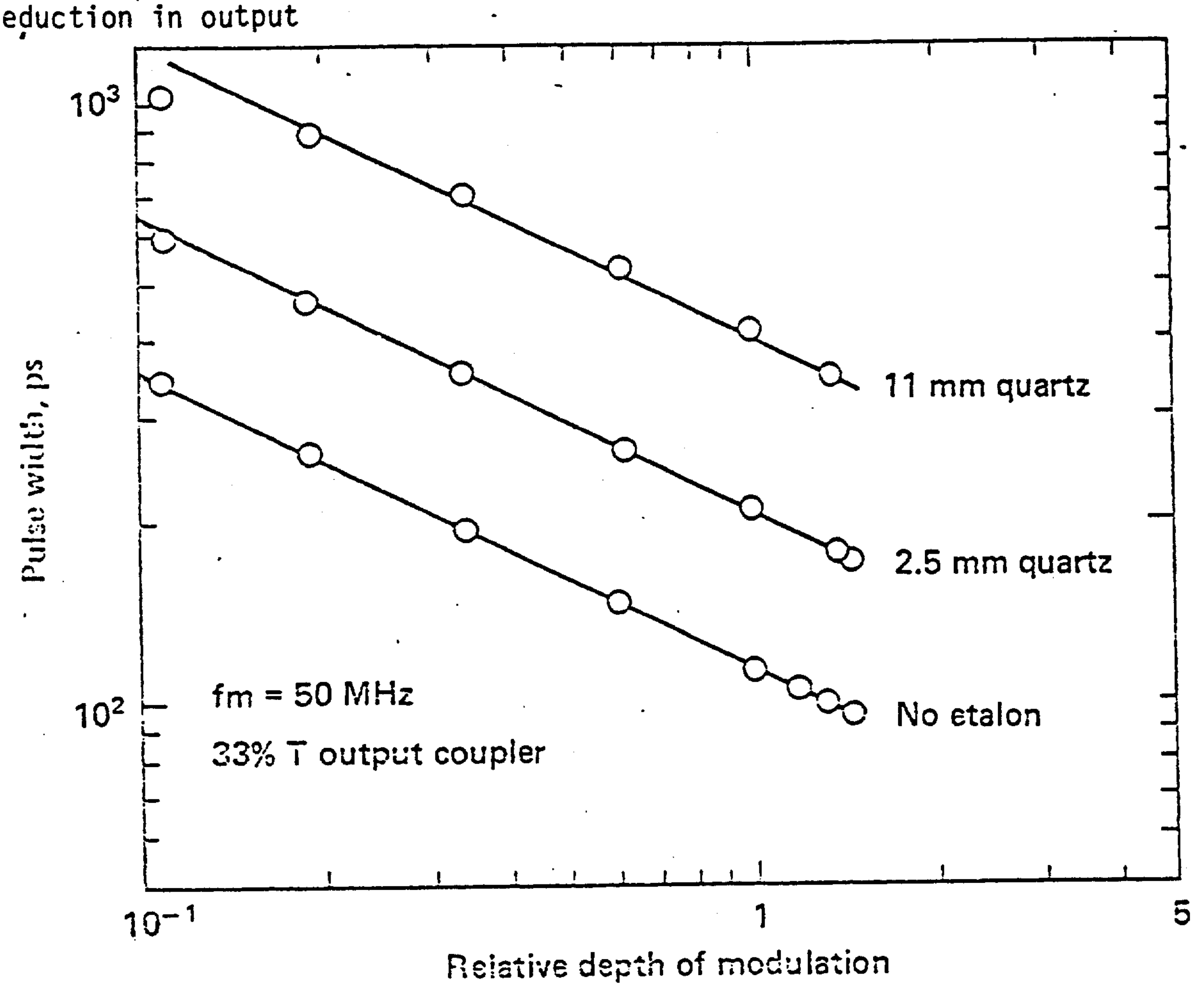


Fig.2 Range of pulses available from Argus Oscillator.

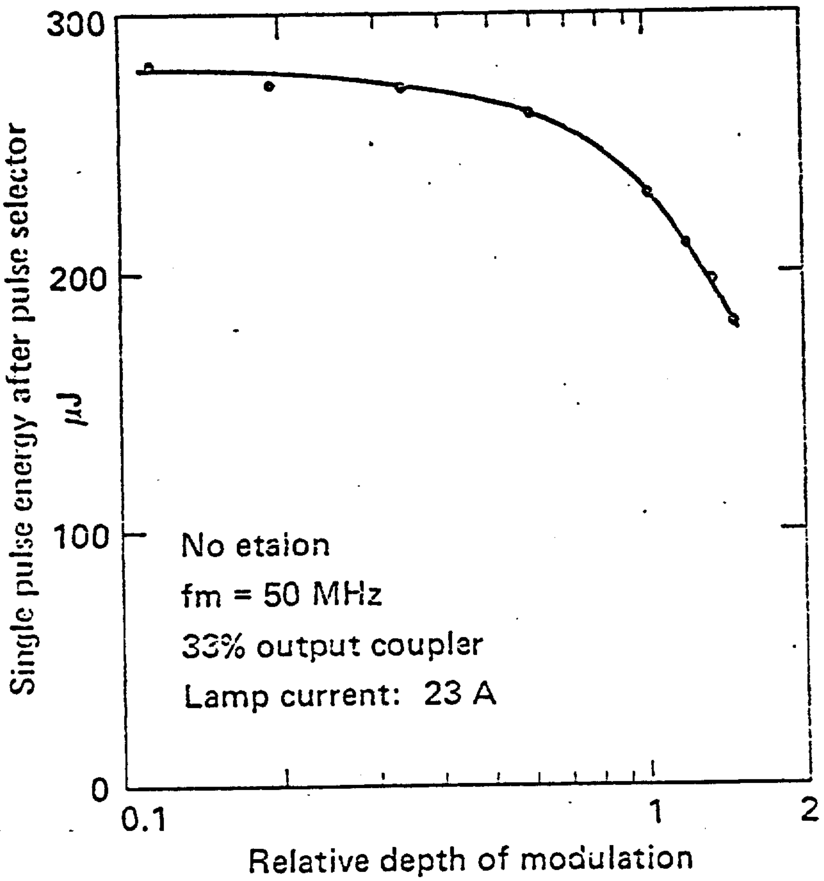


Fig.3 Single pulse energy from Argus Oscillator.

The stability of these oscillators is very good. Typically, over the duration of one hour, the variation of a single selected pulse is less than ± 2%. For the Shiva Oscillator, we have also introduced a new method to switch out a single pulse. We found that the time from when the laser is Q-switched, to a single pulse at the peak of the pulse train is stable to less than one roundtrip in the cavity. Hence we can select this single pulse after a fixed time delay from Q-switching the laser. An avalanche transistor stack is used to drive the KD*P Pockells Cell to select a single pulse. Typically, two or three stages are used in the pulse selector to obtain sufficient pre-pulse isolation.

REFERENCES

1. D. J. Kuizenga and A. E. Siegman, IEEE J. Quant. Electron. QE-6, 694 (1970)

2. D. J. Kuizenga and A. E. Siegman, IEEE J. Quant. Electron. QE-6, 709 (1970).

3. D. J. Kuizenga, D. W. Phillion, T. Lund, and A. E. Siegman, Opt. Commun. 9, 221 (1973).

4. G. V. Krivoshchekov, L. A. Kulevskii, N. G. Nikulin, V. M. Semibalamut, V. A. Smirnov, and V. V. Smirnov, Sov. Phys. JETP 37, 1007 (1973).

5. G. V. Krivoshchekov, N. G. Nikulin, and V. A. Smirnov, Sov. J. Quant. Electron. 5, 1096 (1976).

6. I. V. Tomov, R. Fedosejevs, M. C. Richardson, and W. J. Orr, Appl. Phys. Lett. 29, 193 (1976).

7. I. V. Tomov, R. Fedosejevs, and M. C. Richardson, Appl. Phys. Lett. 30, 164 (1977).

8. D. J. Kuizenga, Opt. Commun. 22, 156 (1977).